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Evaluating Corrective Action Effectiveness Against Incident Recurrence in Mining Operations: A Hierarchy of Controls Approach (2023–2025)

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Abstract
Incident recurrence indicates that organizational learning has not fully succeeded in breaking the chain of failure. This study aims to analyze the relationship between the quality of corrective actions, as measured by the Hierarchy of Controls, and incident recurrence, while accounting for incident characteristics as control variables, at PT XYZ (mining contractor) during 2023–2025. This quantitative study with a retrospective correlational design analyzed 124 incident investigation reports. Critical factors are classified using two schemes presented side by side, namely the company's internal taxonomy and the Human Factors Analysis and Classification System (HFACS). Analyses were conducted at univariate, bivariate (Fisher's Exact Test and Pearson Chi-Square), and multivariate (multiple logistic regression) levels. The reliability of corrective action scoring was validated through inter-rater agreement (weighted Kappa = 0.722; substantial). Results show a high recurrence rate under both schemes (65.3% under HFACS; 72.6% under the internal scheme). Critical Factor was the most dominant predictor (OR = 7.02; $p < 0.001$), followed by Incident Classification (OR = 8.91; $p = 0.003$), while Corrective Action Quality was not significant ($p = 0.556$), consistently across both schemes. Applying the HFACS taxonomy refined the dominant Human Error category (80.6%) into Violation (38.7%) and Error (41.1%), revealing a diversity of failure types useful for improving investigation. The study concludes that the effectiveness of recurrence prevention is determined more by the accuracy of root-cause diagnosis during investigation than by the technical level of corrective actions alone.

Keywords
Incident Recurrence, Corrective Action, Hierarchy of Controls, HFACS, Incident Investigation, Mining

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1. BACKGROUND

The mining industry is one of the sectors with the highest operational risk characteristics, both for personnel and equipment safety. The national regulatory framework, as stipulated in Minister of

Energy and Mineral Resources Decree (No: 1827 K/30/MEM/2018), mandates the consistent application of good mining engineering principles as the minimum operational standard. However, the reality on the ground shows that implementing effective risk controls remains complex. A study by Putri and Denny (2021) found that, despite the implementation of the HIRADC hazard identification process, high levels of risk in mining activities remain frequently identified due to suboptimal control implementation.

In this context, the human factor is often the dominant attribution in mining incident investigations. Qolib and Suroto (2020) documented that incidents in the national mining sector are often attributed to unsafe acts. This finding is corroborated by Winarko (2024), who found that up to 99.7% of incidents in large-scale mining companies are categorized as unsafe acts. However, Hale and Borys (2013) assert that a safety approach based solely on rule compliance, which they call the "Model 1" paradigm, has fundamental structural weaknesses. In a dynamic operational environment like mining, behavioral deviations are often not a manifestation of individual negligence, but rather a reflection of the gap between static, written procedures and the complexity of real-world conditions. Strategies that tighten rules or sanctions without strengthening the system design have proven inadequate to prevent incident recurrence.

This problem is exacerbated by the tendency of accident investigations to stop at the immediate causes. Lindberg, Hansson, and Rollenhagen (2010) highlight that the learning process from incidents is often hampered because investigations fail to explore systemic root causes and instead address superficial causes at the operator's behavioral level. These person-focused investigations tend to result in recommendations for improvement in the form of retraining, reprimands, or counseling—interventions that are least reliable at breaking the chain of failure because they do not address the underlying latent conditions. This weakness can be explained theoretically using the Risk Control Hierarchy. Reason (1997) and Hale (2013) point out a fundamental paradox in safety management: humans are the least reliable system component, yet they are often the primary fulcrum of safety through administrative and procedural controls. A more robust control strategy should move up the control hierarchy, shifting the burden of safety from the individual to the system through engineering or hazard elimination. Without a shift from

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administrative to engineering controls, organizations risk becoming trapped in a cycle of reactive responses that fail to address the root cause.

This dynamic is relevant to study in the operational context of mining contractor. Based on incident investigation report data from 2023–2025, a pattern of incident recurrence was identified for similar types of events, particularly in the property damage category. This raises significant research questions: whether the corrective actions resulting from the investigation process have targeted the appropriate failure mechanisms, and how the characteristics of the incidents themselves contribute to the observed pattern of recurrence. This research therefore departs from the need to empirically understand the relationship between the quality of corrective actions based on the risk control hierarchy and the probability of incident recurrence, by considering incident characteristics as control variables to produce an objective and comprehensive analysis.

2. METHODS

Study Design and Setting

This study employed a quantitative retrospective correlational design to analyze the relationship between corrective action quality, operationalized through the Hierarchy of Controls framework, and incident recurrence in mining operations. The research was conducted at PT XYZ, a mining company in Indonesia, utilizing secondary data from incident investigation reports spanning a three-year period from January 1, 2023, to December 31, 2025. Data collection and analysis were performed between January and June 2026.

Study Population and Sampling

The study population comprised all incident investigation reports documented in PT XYZ's Safety, Health, and Environment (SHE) database during the study period. Using total population sampling, 124 incident reports met the inclusion criteria: (1) classified as property damage or injury incidents, and (2) with documented corrective actions that had been implemented and closed. Near-miss incidents were excluded from analysis as they did not result in actual loss or impact, which could introduce severity bias in the recurrence analysis.

Variables and Measurements

Incident Recurrence was operationalized as a binary outcome (recurrent = 1; non-recurrent = 0). Recurrence was determined through a three-parameter algorithm considering: (1) general incident classification, (2) incident

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mechanism based on MSHA taxonomy (codes 1–8), and (3) sub-mechanism of energy contact adapted from the MSHA Accident Classification Handbook and Program Policy Manual. Two incidents were classified as recurrent only when all three parameters matched, ensuring construct validity through specificity of barrier function principles.

Corrective Action Quality was assessed using a three-tier hierarchy scoring system derived from the Risk Control Hierarchy and barrier function theory: Score 1 (Person-Focused), Score 2 (Soft Barrier), and Score 3 (Hard Barrier). For analytical purposes, Scores 1 and 2 were combined into a single category (Soft/Behavioral Barrier) due to conceptual similarity as behavior-dependent controls and limited frequency of Score 1 cases, resulting in a binary classification: Soft/Behavioral Barrier versus Hard Barrier.

Incident Classification was categorized as property damage or injury. Incident Mechanism was coded according to MSHA taxonomy: (1) Struck by/against/Collision, (2) Loss of Control/Rollover/Overturn, (3) Powered Haulage—Non-Collision, (4) Slip or Fall of Person, (5) Fall of Ground/Highwall, (6) Flying/Falling Object, (7) Machinery/Hand Tools, and (8) Fire/Explosion.

Critical Factor was classified using two complementary schemes presented in parallel. The first scheme followed the company's internal taxonomy: (1) Human Error, (2) Supervisory, (3) Tools, (4) Procedure, and (5) Environment. The second scheme employed a granular classification based on unsafe acts taxonomy operationalized through the Human Factors Analysis and Classification System (HFACS): (1) Violation, (2) Error, (3) Supervisory, (4) Procedure, (5) Tools/Equipment, and (6) Environment. For multivariate analysis, Critical Factor was operationalized as a binary variable distinguishing active failures (Violation and Error) from latent failures (combined Supervisory, Procedure, Tools/Equipment, and Environment), consistent with the Swiss Cheese Model architecture.

Data Collection

Data were extracted from the official SHE Department database using a standardized spreadsheet-based data extraction form. The extraction process involved: (1) obtaining management authorization, (2) identifying all incident investigation reports from the 2023–2025 period, (3) screening reports against inclusion criteria, (4) extracting relevant information into an independent research database, and (5) performing expert

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judgment to convert corrective action descriptions into hierarchy scores. A cross-checking and validation procedure was conducted to ensure data quality prior to coding and statistical analysis.

To ensure objectivity and reproducibility of the corrective action quality scoring, inter-rater reliability was assessed using Cohen's Kappa coefficient. An independent rater from the SHE Department scored all 124 reports without knowledge of the primary researcher's scores, using identical operational definitions. Given the ordinal nature of the three-category scoring, weighted Kappa with linear weighting was employed to account for the degree of disagreement severity. For the binary classification, unweighted Cohen's Kappa was calculated. Kappa values were interpreted according to Landis and Koch criteria. The analysis yielded a weighted Kappa of 0.722, indicating substantial agreement between raters.

Data were analyzed using SPSS statistical software. Univariate analysis described the frequency distribution and percentages of all study variables. Bivariate analysis examined the relationship between each independent variable and incident recurrence using appropriate statistical tests based on table dimensions and data distribution. For 2×2 contingency tables (Incident Classification and binary Critical Factor), Fisher's Exact Test was applied. For larger tables (Corrective Action Quality and Incident Mechanism), Pearson Chi-Square test was used with attention to cells with expected frequencies less than five. Statistical significance was set at $p < 0.05$ (two-tailed). Variables with $p < 0.25$ in bivariate analysis were considered for inclusion in multivariate modeling.

Multivariate analysis employed binomial logistic regression using the Enter method to identify variables that independently determined recurrence probability while controlling for other variables simultaneously. The Enter approach was selected because all predictor variables had theoretical justification from the literature. Model fitness was evaluated through the Overall Model Test, Nagelkerke R^2, and classification accuracy. Incident Mechanism was excluded from the regression model despite bivariate analysis because five of eight MSHA categories had frequencies below five, which could produce unstable coefficient estimates. The final model included three predictors: Corrective Action Quality, Incident Classification, and binary Critical Factor, with reference categories set as Hard Barrier, Injury, and Latent Failure,

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respectively. Effect strength and direction were expressed as Odds Ratios (OR) with 95% confidence intervals.

Ethical Considerations

This study utilized anonymized secondary data from incident investigation reports. Formal authorization was obtained from PT XYZ management and the SHE Department prior to data access. All extracted data were maintained confidentially and used solely for research purposes.

3. RESULTS

Sample Characteristics and Univariate Analysis

A total of 124 incident investigation reports from the period January 1, 2023, to December 31, 2025, met the inclusion criteria and were included in the analysis. All data were complete with no missing values.

Incident Recurrence Rates

Incident recurrence was calculated using two classification schemes. As shown in Table 1, the internal company taxonomy yielded a recurrence rate of 72.6% (n=90), while the HFACS-based scheme showed a slightly lower rate of 65.3% (n=81). The difference stems from the more granular nature of HFACS classification, which requires stricter matching criteria for defining recurrence. Despite this difference, both schemes indicate substantially high recurrence rates exceeding 65%.

Table 1. Distribution of Incident Recurrence Status by Classification Scheme (n=124)

Recurrence Status	Internal Taxonomy n (%)	HFACS Scheme n (%)
No Recurrence	34 (27.4)	43 (34.7)
Recurrence	90 (72.6)	81 (65.3)

Corrective Action Quality

The majority of incidents (77.4%, n=96) received corrective actions classified as Soft/Behavioral Barriers, while only 22.6% (n=28) achieved Hard Barrier status. Recurrence rates showed a descending pattern from Soft/Behavioral Barriers (67.7%) to Hard Barriers (57.1%), consistent with the risk control hierarchy principle that higher-level controls reduce dependence on human behavior reliability.

Inter-Rater Reliability

Inter-rater reliability assessment for corrective action scoring demonstrated substantial agreement. For the three-category scoring, weighted Kappa (linear) was 0.722 (86.3% agreement), and for the binary classification, Cohen's Kappa was 0.709 (87.9% agreement). Both values indicate substantial agreement according to Landis and Koch criteria, confirming the

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reliability and reproducibility of the scoring process.

Control Variables Distribution

Table 2 shows the distribution of control variables. Property Damage incidents dominated the sample (90.3%, n=112) compared to Injury incidents (9.7%, n=12), consistent with open-pit mining characteristics where equipment damage frequency substantially exceeds personnel injuries. Property Damage incidents exhibited a markedly higher recurrence rate (75.9%) compared to Injury incidents (41.7%).

Table 2. Distribution of Control Variables

Variable	Category	n	%	Recurrence Rate
Incident Classification	Property Damage	112	90.3	75.9%
	Injury	12	9.7	41.7%
Critical Factor (HFACS)	Violation	48	38.7	75.0%
	Error	51	41.1	72.5%
	Supervisory	8	6.5	37.5%
	Procedure	3	2.4	33.3%
	Tools/Equipment	6	4.8	33.3%
	Environment	8	6.5	25.0%
Incident Mechanism (MSHA)	Struck by/against/Collision	61	49.2	82.0%
	Loss of Control/Rollover	23	18.5	65.2%
	Powered Haulage – Non-Collision	5	4.0	40.0%
	Slip or Fall of Person	1	0.8	0.0%
	Fall of Ground/Highwall	4	3.2	25.0%
	Flying/Falling Object	22	17.7	50.0%
	Machinery/Hand Tools	3	2.4	0.0%
	Fire/Explosion	5	4.0	40.0%

The HFACS classification revealed that the dominant Human Error category (80.6% under internal taxonomy) could be meaningfully differentiated into Violation (38.7%) and Error (41.1%), providing more balanced distribution and analytical precision.

Regarding incident mechanisms, Struck by/against/Collision events predominated (49.2%, n=61) and exhibited the highest recurrence rate (82.0%). Five of eight mechanism categories had frequencies ≤5 cases; therefore, while analyzed descriptively and in bivariate analysis, Incident Mechanism was excluded from multivariate modeling to maintain estimation stability.

Bivariate Analysis

Bivariate analysis examined the partial relationship between each independent variable and incident recurrence using the HFACS scheme as the primary analysis, with comparison to the internal taxonomy scheme.

Corrective Action Quality and Recurrence

No significant association was found between corrective action quality and recurrence (Fisher's Exact Test, $p = 0.368$). This finding was consistent across both classification schemes (internal taxonomy: $p = 0.479$).

Incident Classification and Recurrence

A significant association emerged between incident classification and recurrence (Fisher's Exact Test, $p = 0.003$). Property Damage incidents demonstrated substantially higher recurrence (69.6%) compared to Injury incidents (25.0%). This pattern remained consistent under the internal taxonomy scheme ($p = 0.018$).

Critical Factor and Recurrence

Critical factor classification showed a highly significant association with recurrence (Fisher's Exact Test, $p < 0.001$). Incidents attributed to Active Failures exhibited a recurrence rate of 73.7%, markedly higher than the 32.0% observed for Latent Failures. This strong, consistent pattern was evident across both classification schemes.

Detailed examination of the six HFACS categories revealed a clear gradient: active failure categories (Violation: 75.0%; Error: 72.5%) demonstrated substantially higher recurrence rates compared to latent failure categories (range: 25.0%–37.5%). Pearson Chi-Square analysis yielded $\chi^2 = 15.702$, $df = 5$, $p = 0.008$, although 50% of cells had expected frequencies <5, warranting cautious interpretation.

Incident Mechanism and Recurrence

Incident mechanism demonstrated a significant association with recurrence (Pearson $\chi^2 = 22.978$, $df = 7$, $p = 0.002$), with 10 of 16 cells having expected frequencies <5. As previously noted, Struck by/against/Collision mechanisms not only dominated the sample but also exhibited the highest recurrence rate (82.0%).

Independence of Predictor Variables

Cross-tabulation of corrective action quality and critical factor revealed no significant association ($\chi^2 = 0.209$, $df = 1$, $p = 0.647$), indicating minimal multicollinearity concerns and supporting the simultaneous inclusion of both variables in multivariate modeling.

Variable Selection for Multivariate Analysis

Following Hosmer and Lemeshow's recommendation ($p < 0.25$ threshold), three variables qualified for multivariate inclusion: Incident Classification ($p = 0.003$), Critical Factor ($p < 0.001$), and Corrective Action Quality (retained as the primary theoretical variable despite p =

0.368). Incident Mechanism, despite bivariate significance ($p = 0.002$), was excluded due to sparse data (five of eight categories with $n < 5$), which would compromise model stability.

Multivariate Analysis: Binary Logistic Regression

Binary logistic regression using the Enter method examined the simultaneous effects of three predictors on incident recurrence: Corrective Action Quality (X1), Incident Classification (X2), and Critical Factor binary classification (X4). Reference categories were established as Hard Barrier (X1), Injury (X2), and Latent Failure (X4).

Model Fit

The overall model demonstrated statistical significance ($\chi^2 = 25.941$, $df = 3$, $p < 0.001$). Nagelkerke R^2 indicated that the model explained 26.0% of the variance in incident recurrence, representing a moderate effect size appropriate for secondary data analysis in occupational safety research. The Hosmer-Lemeshow goodness-of-fit test yielded $p = 0.984$, indicating excellent calibration with no significant difference between predicted and observed values. The model achieved 75.8% overall classification accuracy, successfully predicting 86.4% of recurrence cases and 55.8% of non-recurrence cases.

Predictor Effects

Table 3 presents the multivariate regression results. Critical Factor emerged as the strongest predictor, with incidents attributed to Active Failures having 7.02 times higher odds of recurrence compared to Latent Failures (95% CI: 2.61–18.89, $p < 0.001$), controlling for other variables.

Table 3. Binary Logistic Regression Results Predicting Incident Recurrence (HFACS Scheme)

Predictor	Odds Ratio	95% CI	p-value
Critical Factor (Active vs. Latent)	7.023	2.61–18.89	<0.001
Incident Classification (Property Damage vs. Injury)	8.914	2.15–37.01	0.003
Corrective Action Quality (Soft/Behavioral vs. Hard Barrier)	1.342	0.50–3.58	0.556

Note: Reference categories: Latent Failure, Injury, Hard Barrier. Nagelkerke $R^2 = 0.260$; Hosmer-Lemeshow $p = 0.984$.

Incident Classification also demonstrated significant predictive power, with Property Damage incidents exhibiting 8.91 times higher odds of recurrence compared to Injury incidents (95% CI: 2.15–37.01, $p = 0.003$).

In contrast, Corrective Action Quality did not demonstrate statistical significance ($p = 0.556$), with an odds ratio of 1.342 (95% CI: 0.50–3.58), indicating that the technical level of corrective actions alone did not significantly influence recurrence probability when controlling for critical factor attribution and incident classification.

Comparison of Classification Schemes

Comparison between the two classification schemes revealed that while the magnitude of the Critical Factor effect decreased from OR = 16.247 (internal taxonomy) to OR = 7.023 (HFACS), the HFACS scheme produced a narrower confidence interval (2.61–18.89 vs. 5.46–48.39), indicating more precise estimation. The HFACS scheme also demonstrated superior calibration (Hosmer-Lemeshow $p = 0.984$ vs. 0.698), supporting its use as the primary analytical framework.

4. DISCUSSION

This study provides empirical evidence that the effectiveness of incident recurrence prevention in large-scale open-pit mining operations is determined more by the accuracy of root-cause diagnosis during investigation than by the technical level of corrective actions alone. The finding that Critical Factor attribution (Active vs. Latent failures) emerged as the most dominant predictor of recurrence (OR = 7.02; $p < 0.001$) offers strong empirical validation of Reason's Swiss Cheese Model and underscores the critical importance of investigative depth in organizational learning processes.

The high recurrence rates observed across both classification schemes (72.6% under the internal taxonomy; 65.3% under HFACS) indicate that the organization's Learning from Incidents (LFI) process has not fully transitioned from single-loop to double-loop learning (Argyris & Schön, 1978). This finding aligns with Lukic, Margaryan, and Littlejohn's (2010) assertion that meaningful organizational learning requires structural changes in investigation practices rather than merely procedural additions. The persistence of high recurrence rates despite implemented corrective actions suggests that the organization may be addressing symptoms at the active failure level while leaving latent conditions embedded in system design, policies, and organizational culture unexamined and unmodified.

Critical Factor Attribution and Investigative Depth

The dominance of Critical Factor as a predictor of recurrence represents the most significant contribution of this study. The odds ratio of 7.023 indicates that incidents attributed to Active Failures are approximately 7 times more likely to recur than those with Latent Failures identified, after controlling for corrective action quality and incident classification. This finding provides robust empirical support

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for Reason's (1997) theoretical framework and confirms that stopping investigations at the level of unsafe acts leaves systemic vulnerabilities unaddressed.

The reduction in odds ratio from 16.247 (Scheme 1) to 7.023 (Scheme 2), accompanied by a narrower confidence interval (2.61–18.89 vs. 5.46–48.39), reflects a more conservative and precise estimation when using the HFACS taxonomy. This reduction likely occurs because Scheme 1 used the same factor classification both to define recurrence and as a predictor variable, creating definitional dependency that inflated the effect size. The HFACS-based Scheme 2, with its more granular and independent classification, provides more credible estimates despite the more moderate effect magnitude.

The descriptive data further illuminate this relationship: among 99 incidents attributed to Active Failures, 73 (73.7%) recurred, whereas only 8 of 25 incidents (32.0%) attributed to Latent Failure recurred. This substantial difference underscores the protective effect of deep investigative practices that penetrate beyond surface-level explanations. The tendency to terminate investigations at the unsafe acts level represents a universal challenge in incident investigation culture (Shappell & Wiegmann, 2000), and Hopkins (2000) correctly notes that attribution patterns often reflect investigative depth rather than true causal structures.

The Paradox of Non-Significant Corrective Action Quality

One of the most intriguing findings of this study is the lack of statistical significance for Corrective Action Quality (X1) in predicting recurrence ($p = 0.556$ in multivariate analysis), despite a descriptive pattern consistent with risk control hierarchy theory. The recurrence rate was lower for Hard Barriers (57.1%) compared to Soft/Behavioral Barriers (67.7%), aligning with Reason's (1997) principle that higher-level controls reduce dependence on fallible human behavior. However, this pattern did not achieve statistical significance.

This apparent paradox can be explained through several interconnected mechanisms. First, the uneven distribution of data, with only 28 incidents (22.6%) in the Hard Barrier category versus 96 incidents (77.4%) in the Soft/Behavioral category, limited the statistical power to detect differences (Hosmer & Lemeshow, 2000). Second, and more importantly, the effectiveness of any barrier depends on its placement at the correct point of failure. Hale and Borys (2013) emphasize that barrier quality alone does not guarantee

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protection if the barrier is not positioned at the appropriate failure point. Hollnagel (2004) further argues that the barrier function is specific to the energy release mechanism it targets; thus, a technically superior hard barrier designed based on an inaccurate diagnosis will have limited effectiveness.

This finding challenges the simplistic assumption that implementing higher-level controls automatically reduces recurrence. Instead, it supports Drupsteen, Hasle, and Zwetsloot's (2013) argument that the effectiveness chain of corrective actions begins with investigation quality rather than barrier quality. Dekker (2006) reinforces this perspective by asserting that human error should not be the endpoint of investigation but rather the starting point for understanding why actions made sense to actors at the time. The non-significance of X1 should therefore not be interpreted as evidence against the hierarchy of controls but rather as evidence that diagnostic accuracy moderates the relationship between barrier level and effectiveness.

Incident Classification and Severity Bias

The significant effect of Incident Classification (OR = 8.914; p = 0.003) empirically confirms the phenomenon of Severity Bias predicted by Accident Pyramid Theory (Bird, 1969; Heinrich, 1931). Property Damage incidents demonstrated approximately nine times higher odds of recurrence compared to Injury incidents, despite receiving comparatively less investigative attention. This finding aligns with the work of Phimister, Oktem, Kleindorfer, and Kunreuther (2003), who documented that organizations disproportionately allocate investigative resources to high-consequence events while neglecting lower-sequence incidents.

Given that 90.3% of incidents were classified as Property Damage with a high recurrence rate (69.6%), there exists a substantial opportunity to strengthen investigation processes for this category. Kletz (1993) emphasized that every Property Damage incident serves as a precursor event that, if addressed seriously, can prevent it from evolving into more serious incidents. The finding suggests that establishing equivalent investigation depth standards for both Property Damage and Injury incidents could represent an efficient prevention strategy.

HFACS Taxonomy and Enhanced Diagnostic Capability

The application of the HFACS taxonomy revealed important nuances obscured by the company's internal

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classification. The single "Human Error" category (80.6% under internal taxonomy) was meaningfully differentiated into Violation (38.7%) and Error (41.1%), enabling more targeted interventions. This distinction is theoretically and practically significant: following Reason (1990), Errors are unintentional mistakes resulting from cognitive limitations that can be reduced through training, design improvements, or task simplification, whereas Violations are intentional deviations stemming from motivation, risk perception, and safety climate and require different intervention strategies.

The substantial proportion of Violations associated with speed violations, operating equipment without proper safeguards, and operating under fatigue without reporting indicates potential issues with the safety climate and reporting culture that warrant organizational-level attention. This finding aligns with Kjellén's (2000) assertion that the granularity of taxonomy determines the effectiveness of learning from incidents. Patterson and Shappell (2010) reported similar findings when applying HFACS to 508 mining incidents in Queensland, demonstrating that layered frameworks reveal systemic factors invisible to macro-level classifications.

Recurrence as a Systemic Challenge

The high recurrence rates observed in this study are not unique to this organization. Sanmiquel, Freijo, Edo, and Rossell (2010) documented that incident recurrence represents a systemic challenge facing the majority of mining companies, particularly in large-scale open-pit operations. Reason's (1997) concept of organizational accident explains that recurring incidents often result from latent conditions embedded in operational system design rather than individual negligence alone.

The difference in recurrence magnitude between the two schemes reflects the sensitivity of recurrence measurement to the granularity of the critical factor taxonomy used to define it. This finding is a starting point for strengthening organizational learning mechanisms rather than merely a performance metric. From an organizational learning perspective, high recurrence rates across both schemes indicate an incomplete transition from surface to deep learning, requiring fundamental changes in how the organization conducts investigations.

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Incident Mechanism Patterns and Strategic Implications

Although Incident Mechanism (X3) was excluded from multivariate modeling due to sparse data (five of eight MSHA categories had frequencies <5), the descriptive and bivariate findings carry strategic importance. The dominance of Struck by/against/Collision mechanisms (49.2% of all incidents) and their highest recurrence rate (82.0%) indicate that traffic management and proximity control systems in operational areas represent priority intervention areas with the highest potential return on prevention investment.

Haddon's (1980) energy damage theory emphasizes that interventions for collision mechanisms must be tailored to specific energy contact subtypes, as each sub-mechanism requires different barrier approaches. The concentration of nearly half of all incidents in a single mechanism category suggests that system-level interventions targeting traffic management, proximity detection technology, and haul road design could yield substantial reductions in overall incident rates.

Integration with Incident Learning Cycle Framework

The configuration of findings is consistent with the Incident Learning Cycle framework proposed by Drupsteen, Hasle, and Zwetsloot (2013), which emphasizes that corrective action effectiveness is a downstream variable highly dependent on upstream variables—specifically, investigation depth and root-cause diagnosis accuracy. When investigations produce deeper attributions (latent failures), recurrence decreases substantially. Conversely, when investigations stop at the active failure layer, recurrence remains high regardless of the applied barrier level.

This framework explains why Critical Factor emerged as the dominant predictor while Corrective Action Quality did not reach significance. The model Nagelkerke R^2 of 0.260 and classification accuracy of 75.8% indicate moderate explanatory power, appropriate for secondary data analysis in occupational safety research (Hosmer & Lemeshow, 2000). The consistency of findings across both classification schemes strengthens the validity of conclusions, demonstrating that patterns are not artifacts of a single recurrence definition.

Limitations

Several limitations warrant acknowledgment. First, the uneven distribution of Corrective Action Quality data limited statistical power to detect

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significance despite theoretically consistent patterns. Second, the concentration of Critical Factor distribution necessitated binary reconstruction before multivariate analysis, preventing individual testing of granular differences among latent failure subcategories. Third, the exclusion of Incident Mechanism from multivariate modeling due to sparse data means that its independent effect, while significant in bivariate analysis, could not be quantified while controlling for other variables.

Fourth, as a secondary data analysis, the quality of variable classification depends entirely on the depth and consistency of field investigation processes. Although expert-judgment validation was conducted, the possibility of inter-investigator interpretation variation cannot be ruled out. Fifth, the HFACS re-classification was conducted through narrative review by researchers; although guided by established frameworks, interpretive variation remains possible despite minimization through validation procedures.

These limitations suggest that findings should be interpreted as indicative rather than definitive. That replication with larger samples, more balanced distributions, and prospective data collection would strengthen confidence in the observed relationships.

Implications and Recommendations

The findings carry several constructive implications for occupational safety practice in mining operations. First, strengthening investigation methodology represents the highest-leverage intervention. Given the dominant influence of Critical Factor attribution on recurrence (OR = 7.02), investment in enhancing investigation competency, particularly the ability to systematically identify latent failures, offers the greatest strategic impact. Systematic application of frameworks such as HFACS (Shappell & Wiegmann, 2000) can help investigators structurally transcend the attribution of active failure while distinguishing between Violations and Errors that require different interventions.

Second, equalizing investigation depth for Property Damage incidents is essential. With an odds ratio of 8.91 for incident classification, establishing minimum investigation depth standards applicable equally to Property Damage and Injury incidents could effectively capture early warning signals (Kletz, 1993) and prevent escalation to more serious consequences.

Third, prioritizing Struck by/Collision mechanism interventions offers the highest return on investment for prevention. With 49.2% of incidents and 82.0% recurrence, a comprehensive evaluation of traffic management systems, proximity detection technology, and haul road design based on energy contact sub-mechanisms can guide more precise intervention design.

Fourth, refining cause classification systems to distinguish failure types more precisely, particularly the substantial Violation proportion, can inform more targeted interventions that address both technical aspects and safety climate/reporting culture dimensions.

5. CONCLUSION

This study demonstrates that organizational learning effectiveness in preventing incident recurrence depends primarily on investigative depth and diagnostic accuracy, rather than on the technical sophistication of corrective actions. The dominant predictive power of Critical Factor attribution validates the Swiss Cheese Model and underscores the imperative of penetrating beyond active failures to address latent conditions. The non-significance of Corrective Action Quality, despite theoretically consistent patterns, reveals that barrier effectiveness is moderated by diagnostic precision. These findings challenge organizations to invest in investigation capability development as the foundational element of effective learning from incidents, with implications extending beyond mining to other high-risk industries seeking to strengthen their safety management systems..

AUTHOR CONTRIBUTIONS

ZSM and AA was responsible for conceptualization, design, data collection, data analysis, and manuscript preparation. XX supervised the research process, contributed to the methodological design, and critically revised the manuscript. ZSM contributed to data interpretation and provided critical review and final approval of the manuscript.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest in this research.

DATA AVAILABILITY STATEMENT

The data are available from the corresponding author upon reasonable request.

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